Biological Fabrication of Hierarchically Structured Materials from Protein Condensates

Nature provides an important role model for inspiring sustainable production of high-performance polymeric materials. For example, mussels rapidly fabricate hierarchically structured biopolymeric fibers known as byssal threads, which have emerged as an important source of bio-inspiration due to their remarkable material properties (e.g., high toughness, self-healing, wet adhesion). Understanding the physical and chemical principles underlying byssal thread production may inspire greener materials fabrication in the future; however, currently, these design principles must first be elucidated.

Byssal threads are produced via bottom-up self-assembly of over 15 different protein building blocks, which localize in specific regions of the fiber with nanoscale precision. The threads themselves consist of different functional regions including an underwater glue, a self-healing fiber, an abrasion-resistant flexible coating, and a quick-release biointerface. Our group has harnessed advanced material characterization techniques, including confocal Raman spectroscopy, X-ray fluorescence microscopy and focused ion beam scanning electron microscopy (FIB-SEM), coupled with traditional biochemical approaches to investigate the fabrication of these different components. We have discovered that mussels employ secretory vesicles filled with condensed fluid protein phases (e.g., coacervates, liquid crystals) as precursors for byssus assembly. These dynamic fluid phases enable the pre-organization of protein building blocks, which respond to specific chemical and physical triggers (pH, redox potential, ion content, mechanical shear) to initiate the “fluid-to-solid” transformation. In the adhesive, protein condensates are secreted into a network of channels resembling a microfluidic device, where they undergo liquid-liquid phase separation (LLPS) and are simultaneously cross-linked via coordination complexation with co-secreted metal ions (Fe and V). Extracted design principles hold direct relevance for inspiring production of advanced polymeric materials and adhesives.

BIOGRAPHY
Matthew Harrington is Professor and Canada Research Chair Tier 2 in Green Chemistry in the Department of Chemistry at McGill University, as well as co-director of the McGill Institute of Advanced Materials (MIAM) and director of the McGill Chemistry Characterization (MC²). He received his Ph.D. in 2008 from the University of California, Santa Barbara in the lab of J. Herbert Waite. This was followed by a Humboldt postdoctoral fellowship at the Max Planck Institute of Colloids and Interfaces in the Department of Biomaterials, where he was later a research group leader from 2010 until 2017. His research is focused on understanding biochemical structure-property relationships in the function and formation of biological materials and applying extracted design principles for the development and sustainable production of bio-inspired materials.